PATENT SPECIFICATION 792,145

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COMPLETE SPECIFICATION.

Improvements in and relating to Devices for Obtaining a Mechanical Movement from the Action of an Electric Current.

We, TECHNOGRAPH PRINTED CIRCUITS LIMITED, a British Company, of 32 Shaftesbury Avenue, London, W.1, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to devices for obtaining a mechanical movement from the action of an electric current, using the thermal effect of the current.

If an elongated elastic heat conductive member thin in relation to its length has mounted on one face in relatively good heat conductive connection, but electrically insulated from it, an electrical conductor of considerable dimensions parallel to the length of the elastic member but of small dimensions in a direction normal to the face of the elastic member, and a current heavy enough to produce a substantial heating effect is passed through the conductor, the heat is asymmetrically dissipated in the elastic member, causing it to undergo a change of form of substantial character by bending, the effect decreasing though not disappearing as the heating of the elastic member becomes more uniform. The initial bending can be increased and the rate of decrease reduced by incorporating a longitudinal layer of insulation within the elastic member.

It will be readily understood that the conductor need not be on the face of the electric member but can be within it provided that the dimensions of the conductor are as above specified and that the association between the conductor and the elastic member is such that the elastic member is asymmetrically heated.

It will also be readily understood that the elastic member need not be of elongated form but may be of disc form in which case the member instead of bending under the asymmetric heating effect will change its form from flat to convex on the more highly heated side or in more general terms increase its convexity on that side. In this case the conductor may extend in two dimensions on or within the elastic member, while still being of small dimensions normal to the surface of the elastic member and the expression "surface direction" will be used to denote the large dimension(s) of the conductor whether associated with an elongated or disc form of elastic member.

An object of the present invention is to increase substantially the change of form of an elastic member when asymmetrically heated by the aid of a conductor arranged as above described.

According to one aspect of the invention mechanical forces (which may be externally applied or may be internal forces) come into action for the purpose, and according to another aspect of the invention the elastic member is a bimetallic member, the arrangement being such that the part which is more highly heated by the asymmetric dissipation is the part of higher coefficient of expansion. As will be explained later such a bimetallic device can be made independent of ambient temperature variations. In both aspects of the invention as compared with mere asymmetric heating a substantial increase in the change of form takes place though in the case of a bimetallic member the changes of form due to the respective cases cannot be distinguished from one another.

When mechanical forces are employed the total change of form has two distinct com-

ponents, one which for convenience will be referred to as the primary change, due to the asymmetric heating effect above described, and the other which for convenience will be referred to as the secondary change, due directly to the mechanical forces. To attain the desired purpose these forces are arranged to act in such a way that the secondary change of form is substantial and in the same sense as the primary change so that the two changes supplement one another. Thus the primary change of form may cause the elastic member to pass through a dead-centre position at which forces come into action to produce the secondary change. If these forces are external to the elastic member they will continue to hold the elastic member substantially in its changed form when the current ceases and the heating effect disappears, and the device will result in a persisting mechanical movement being derived from the temporary action of an electric current.

Again, the elastic member may be in a labile condition due to stresses locked within it so that it will spring suddenly from one configuration to another when slightly deformed, in which case if the primary deformation is sufficient, when it takes place the elastic member will spring suddenly from the one configuration to the other.

Other features of the invention will appear as the description proceeds, reference being made to the accompanying drawings in which for the sake of clearness the thicknesses of the various parts are greatly exaggerated.

Figures 1 to 4 show four simple examples of structures which may be used in practising the invention;

Figures 5 to 8 show four examples of the invention in which a bimetallic member is used;

Figure 9 shows an alternative to Figure 1;

Figure 10 shows a further development;

Figure 11 shows another form;

Figures 12 and 13 show a form of the invention in which a secondary change of form is produced by external forces and is maintained thereby until released;

Figures 14 and 15 show developments of the simple forms shown in Figures 1 and 3; and

Figures 16 and 17 are elevations taken at right angles to the previous figures showing possible arrangements of the conductor.

A simple way of producing an asymmetrical dissipation of heat with the consequent primary change of form called for by the invention is by the physical location of the conductor and a particularly simple form is that shown in Figure 1, in which a thin conductor 11 is mounted on one long face of a bar-like member 12 of elastic material, a thin layer 13 of insulation being if necessary interposed. Since the voltages involved need not be very high the insulation can be very thin and thus not hinder the dissipation of heat into the member 11, although as a general rule electrical insulators are also heat insulators.

The asymmetrical dissipation can also be produced by using an elastic bar of non-uniform heat conducting nature, for instance of laminated structure with one or more of the laminations of less heat conductivity than others. In Figure 2, for example, the elastic bar is a laminated structure made up of two metallic bars 14, 15, separated by heat insulation 16. On the face of the member 14 is the conductor 17 insulated by a thin layer of insulation 18. Clearly when current is passed through the conductor 17 the transmission of heat from the member 14 to the member 15 is slowed down by the layer 16.

In both Figures 1 and 2 the conductor being entirely on one side is necessarily located in physical asymmetrical relationship to the elastic member but other dispositions in particular within the elastic member are also possible which will result in an asymmetric heating and therefore a bending of the bar when a current passes through the conductor. Thus with the conductor within the elastic member, even if the conductor is symmetrically disposed within an elastic member of uniform heat conductivity, asymmetric heat dissipation can be obtained by the provision of different boundary conditions at the faces of the elastic member on opposite sides of the conductor. Thus as shown in Figure 3 there may be a conductor 19 between two similar elastic bars 21, 22 with similar thin layers of insulation 23, 24 interposed. But on the bar 22 only is provided a heat insulating or reflecting layer 25 while the corresponding face of the member 21 may be treated or coloured to render it radiating. Thus when current is passed through the conductor 19 the member 22 becomes hotter than the member 21, with corresponding elastic deformation of the structure. Figure 4 shows another example, in which parts which correspond with Figure 3 have the same references but in this case the surface of the member 21 is in contact with a flowing liquid 26. The structure is assumed clamped at its lower end and to allow elastic deformation the wall 27 of the liquid duct is made flexible. The elastic member itself is hereof physically symmetrical construction as in Figure 3.

In many cases the elastic heat conductive bar will primarily be of metal, though if a laminated structure is used the metal will be laminated with a material usually non-metallic which has low heat conductivity, as already indicated above in the description of Figure 2.

In use in many cases the conductor will only transmit current when it is desired to produce the change of form for some purposes to be achieved or some indication to be given. But cases are also possible in which the conductor normally carries current and the device normally remains in an equilibrium condition with its external surroundings; it will then undergo a change of form when the current is cut off.

It will be understood that the above-described section of the conductor constituting a heating element and the fact that the elastic member with which it is associated is in general a good conductor of heat, enables a comparatively heavy current to be used, and therefore a considerable heating effect to be achieved; moreover, an elastic member is able to undergo deformation and recover its original form, or substantially recover its original form, many times without suffering damage.

It will also be understood that in the devices above described with reference to Figures 1 to 4 if the current is maintained the primary deformation will reach a certain value and then, as the heating of the elastic member becomes more uniform, some of this deformation will disappear; after a certain time an equilibrium condition will be reached under which there will still be a certain primary deformation because the metallic member is being heated asymmetrically, but just because a good conductor of heat is used, when equilibrium conditions are reached the deformation will not be very great.

A particular property of a device of this character is that it is substantially insensitive to ambient temperature conditions. It is true that if the heating element and the elastic member are of different metals the asymmetry of the arrangement would theoretically cause slight deformations with ambient temperature changes, but just because the conductor is thin in a direction normal to the elastic member, any constraints which it exerts due to differences of thermal coefficient of expansion would have little effect on the elastic member, especially if, as may be desirable, the form of the conductor is made such as to keep such constraints to a low value. This property of the device makes it useful for many purposes where, for example, a bimetallic strip heated by the passage of a current is not suitable.

In one aspect of the invention the elastic member itself is a bimetallic strip, bar or the like, the heating element being arranged so that the greatest heating effect due to the heating element is on that side of the bimetallic member which expands at the greater rate.

A simple form is illustrated in Figure 5, in which a bimetallic strip consisting for example of a brass element 28 and a steel element 29 is shown in the form of a cantilever fixed at one end. When such a strip is heated it would bow to the left in the figure, because the coefficient of expansion of brass is greater than that of steel. In applying the present invention, therefore, a thin conductor 31 is applied to the brass element 28 with the interposition of a thin layer 32 of insulation. If this structure is now heated by passing a current through the conductor 31 the bimetallic strip is not only heated but it is heated asymmetrically and in this way therefore a substantially greater deformation for a given power input is obtained and a greater force can be obtained. Thus, a more efficient device can be produced, or for a given movement a more rapid response. Independence of ambient temperature conditions can still be obtained by providing a second bimetallic strip having the same law of deformation as the first, but without a heating element and using it to compensate those movements of the first bimetallic strip which are due to ambient temperature changes.

If, for example, as in Figure 6, two bimetallic cantilevers 33, 34, one of them being constructed exactly as in Figure 5 and the other consisting only of the bimetallic cantilever identical with that used in the first, are arranged in parallel and their free ends are joined by a telescopic member 35, under the action of a spring, then no changes in the force exerted on this member will occur under ambient temperature changes but they will occur if a current is passed through the heating element 36. In the form shown when the current is passed through the heating element 36 the member 33 will bend to the left. Thus if the member 35 has a pair of contacts carried by its respective parts which are closed, they will then open. The opposite effect would be obtained if the member 36 were provided on the member 34. Alternatively, as shown in Figure 7 the free end of a first bimetallic member 37 is linked to the clamped end of a second bimetallic member 38 of similar construction and dimensions to the first. The clamped end of the member 38 may for example be mounted in a slide block 39 moving in guides 41. The two members 37, 38 are arranged oppositely so that when there is an ambient temperature change the movement due to the deformation of one of them is exactly equal and opposite to that of the other and accordingly the outer end of the member 38 remains in constant position. Either (or both) cantilevers is provided with an insulated conductor in accordance with the invention and by energising one of them a deflection of the outer end of the member 38 can be obtained.

Other relative arrangements on the same

principles are also possible. In the case of bimetallic strips as long as the heating element is in action there will be a considerable deformation even when equilibrium is reached.

There will, in general, be a time lag between the switching on of current and the maximum deformation and this, in turn, will put a limit on the frequency at which the device can be used, but the time lag is small enough and the frequency high enough for the device to be useful for very many purposes. The actual time lag can be varied by choice of the dimensions, materials and actual construction of the elastic member and the heating element.

The extent of deformation can be substantially increased by interposing a thin layer of heat insulating material at a place within the elastic member which hinders the transmission of heat to that part of the metallic member which in any case would be last heated during the passage of current through the conductor. An example is above described with reference to Figure 2.

This development could be used in association with a bimetallic member which in this case would become a sandwich of two different metals on opposite sides of the layer of heat insulating material.

An example is illustrated in Figure 8. Here there are two elements 42, 43, one say of brass and the other of steel, with a thin conductor 44 between them. Between the conductor 44 and the brass element 42 is a thin layer of electrical insulation 45 while between the conductor 44 and the steel element 43 is a thicker layer 46 of material which is both an electric insulator and a good heat insulator. When current is passed through the conductor, more heat is dissipated into the brass than into the steel and the deflection of the whole structure is substantially greater than it would be if it were uniformly heated.

The elastic member can be of bar form with the conductor secured on one long face as in the above described examples; desirably also as shown in the above examples, the conductor extends over a substantial part, or even the whole of the long side of the bar. The deformation in the case of Figure 1, for example, is not very great, but the time lag is very small. If the primary deformation is to be increased by the use of a layer of insulation, the layer of insulation can extend as in Figure 2, within the bar parallel with the face on which the conductor is provided; it can, for instance, be halfway through the thickness as shown in Figure 2, so that in effect in the latter case the bar becomes a sandwich of two bars with a thin layer of thermal insulation between them and with an insulated conductor secured on the exposed long face of one of the bars. With such constructions, the deformation occurring on heating is a change of curvature of the bar in planes normal to the face carrying the conductor. Generally speaking, the bar might be straight when no current is flowing, and it will then become curved. If a bar of this kind is clamped at one end the other end will move laterally when the deformation occurs; if it is clamped in the middle as indicated at 47, Figure 9, both ends will move laterally; in effect it will be two cantilevers operating in parallel and the movement of each half can constitute a separate primary deformation.

It is also possible as shown in Figure 10 to make a sandwich construction in which the conductor is between two bars 48, 49 of the same elastic material; on one side the conductor 51 is secured as close to the bar 48 as is compatible with electrical insulation 52 while on the other side a layer 53 is provided which is not only an electrical insulator but also provides a substantial heat insulation, so that once again the composite bar is heated asymmetrically and will deform similarly to the constructions of Figures 1 and 2 described above. It will be understood that with these sandwich constructions, though the deformation is greater, the time lag is also greater than in the case of a simple bar.

The examples above described are of bar form but it is also possible to embody the invention with an elastic member of disc form, in which case the deformation will be a change in convexity and may be from a flat form to a convex form when the current passes. In this case the conductor may take a spiral form or preferably, as shown in Figure 11, a double spiral 55 may be used so as to avoid inductive effects. In this figure the disc is indicated at 54.

The use of the devices above described with reference to Figs. 1 to 4 and 9 to 11 to embody the invention requires mechanical forces to come into action to produce a secondary change of form. If it is desired that the elastic member once having been deformed should remain so after the current has been cut off and until some other operation, generally a mechanical operation, is performed, this can be effected by preloading the member in a condition and under a load such that when the current passes the member is moved over a dead centre. For example, a bar can be held under endwise pressure, or a disc under radial pressure, which bows it slightly in a direction opposite to the bowing produced by the heating effect; then when heating has bowed it the other way, the end pressure or radial pressure will increase the bowing and continue to hold it bowed in this opposite direction after the current has been cut off.

Figures 12 and 13 illustrate this. In

Figure 12 an elastic bar 56 having pointed ends is normally slightly bowed upwards and is mounted between the two parts 57, 58 of a bracket which are mutually guided and are drawn towards one another by a spring 61. The bar 56 is for the sake of simplicity shown as in Figure 1 with a conductor 62 insulated by a layer 63 on one face. This is the face which is normally concave. When a current is passed through the conductor the asymmetric heating causes the concave face to expand more than the convex face and the bar 56 now bows in the opposite direction, as shown in Figure 13. But in this form of the invention when the heating effect disappears the bar remains bowed as in Figure 13 by the action of the spring 61. It will be understood that the strength of the spring must be such as will permit the bar to change its curvature to pass from the condition of Figure 12 to that of Figure 13 but to prevent the bar from returning to its original form when the heating effect disappears. Some additional means not shown will be provided for releasing the action of the spring sufficiently to enable the bar to return to its original form when desired.

While Figures 12 and 13 illustrate the particular case of a bar, a similar construction can comprise a disc with spring means acting radially. Thus there could be a multi-part bracket engaging spaced points round the periphery of the disc, the parts being drawn together by a spring equivalent to the spring 61.

Another possibility of bring mechanical forces into action to produce a secondary change of form is to use an elastic member generally of metal which by means of stresses locked in the material is in a labile condition. Known devices of this kind are oil-can bottoms and snap lids in the case of discs and the blades of micro-switches in the case of members of bar or strip form. By providing a device of this character with a heating element which produces a primary change of form a much increased total deformation can be obtained but in this case, in general, when the heating is stopped the device will return to its starting position. In these cases the greater part of the movement takes place suddenly which may be of advantage when the device is used for electric switching, e.g., as a relay.

A further development of the aspect of the invention which requires mechanical forces to come into action to produce a secondary change of form is to provide a bar member or disc of the simple form shown in Figure 1 or the sandwich form shown in Figure 2, with a conductor on both sides. Figure 14 is an example in which there is a sandwich comprising two elastic bars 64, 65, with a layer 66 of heat insulation between them. There is here an insulated conductor 67, 68 respectively on each side. Again, a bar member or disc of a sandwich form based on that shown in Figure 10 can be provided with a conductor on both sides of the thermal insulating layer, as shown in Figure 15, where the conductors are marked 69, 71 respectively, 72, 73 being the elastic members, 74 75 the insulation and 76 the heat insulator. In Figures 14 and 15 only one conductor will be energised at a time, but by choosing which is energised, the member can be deformed to one side or the other. A secondary change of form will be produced as before by mechanical forces coming into action when the deformation due to heating by the conductor takes place.

The conductor itself can be produced in various ways. It is very conveniently produced by printing, since a printed conductor can easily be given the necessary characteristics of thinness normal to the surface on which it is printed, and any desired width on the surface. And of printed conductors, conductors produced in accordance with Patent No. 639,178 are particularly well adapted to the purpose in view. It has been found, for example, that a conductor of cupronickel foil of ½ mil. thick of a zig-zag form produced in this way on a thin support of a synthetic resin, e.g. an epoxy resin as sold under the Registered Trade Mark "Araldite", and secured to a metallic bar member by a cement such as used in the securing of electrical resistance strain gauges can without difficulty dissipate into the metal bar the heat derived from a loading of well over 10 watts per square inch.

As above noted, it may be desirable to arrange the conductor in such a way that it is not harmed and does not exercise substantial elastic constraint on the metallic member. This can be done by arranging the conductor in a zig-zag or grid iron pattern in which the limbs extend transverse to the length of the metallic member. Such an arrangement is shown in Figure 16, where the conductor 77 is of grid formation. In some cases, however, it may be desirable that the conductor should be elastically strained as the member deforms. In this case, as shown at 78 in Figure 17, the grid iron or zig-zag limbs would extend lengthwise of the metallic bar, in which case the heating and deformation should be limited to a value which avoids damage. This arrangement may be used, for instance, where it is desired to keep a check at some remote point on the amount of deformation, or use this indication of the amount of deformation to control another circuit. This can be done by using the conductor not only as a heating element but also to actuate the sort of circuit which is used with a strain gauge. However, the former arrangement in which the grid-iron or zig-zag limbs are

transverse to the length of the metallic member can also be used to give a remote indication or control by using the conductor not only as a heating element but also as a resistance thermometer. In the former case, the temperature of the conductor, as well as the strain of the conductor, would affect the readings and must therefore be taken into account. In the latter case, the temperature of the conductor can be ascertained but no direct indication of the amount of deformation.

A valuable feature of the device according to the invention in which mechanical pressure used is that is can exert considerable forces when undergoing its primary change of form because in general metals have a high modulus of elasticity and the forces exerted are directly related to this modulus. In the case of a bimetallic member the forces are high over the whole movement.

The device according to the invention can be used for many purposes. In general it can be used for example to replace a simple bimetallic strip wherever such a strip is heated by the passage of an electric current. The device can be used as a relay in which case it will usually be of lighter and cheaper construction than an electromagnetic relay. In a larger size it can be used as a contactor to control heavier currents than can be directly controlled by a relay just because as above pointed out it is capable of developing large forces. It can be used for the construction of switches and relays with a wide range of time lag from very small up to such long delays as would not readily be achieved with ordinary electromagnetic relays. In this case of relays and switches a quick closing and opening action, independent of the actual time lag, and a large break can be obtained by the use of an elastic member in a labile condition as above described. The device can be used as an automatic interrupter of comparatively low frequency by making its movements control the flow of current through its own heater.

The device can be used as a circuit breaker which remains open once it has operated until it is re-set manually or by some other piece of apparatus. For this purpose, the type described above, with reference to Figures 12 and 13 for example, which is preloaded and moves over a dead centre when current passes, would be used.

Since the response of the device depends on the current in the heating element a device according to the invention can be made to distinguish between low currents and high currents and this is especially valuable in an automatic circuit breaker used for protective purposes. The device can also be used as an indicator in the like circumstances where it is not necessary that a circuit should be broken but simply that an indication should be given when there is a sudden increase in current in a circuit, or a part of a circuit; for example, it can be used to indicate the occurrence of a temporary short circuit; here again, the use of an elastic member in a labile condition may be of advantage in particular cases. The device can similarly be used to indicate the breakage of a current carrying element where that element is included in a bridge circuit. If the element breaks the bridge is thrown out of balance by a vast amount because a finite resistance in one arm is suddenly made infinite. There is accordingly an immediate substantial current increase in the output diagonal of the bridge. If the heater of a device according to the invention is included in the diagonal, this sudden increase will actuate the device, thus giving a remote signal, or causing some operation to be performed, whereas the normal current in the diagonal while the bridge is only out of balance to the extent caused by the resistance variations in the arms will not affect it.

Another possible use for the device according to the invention is as an indicator of the flow or temperature of a flowing medium such as a liquid. In this case, the flowing medium will influence the heat carried away from one face of the device. For instance, it may flow past it as in Figure 4 and the heating element will usually be continously energised. Changes in the rate of flow and/or the temperature of the medium will influence the asymmetry of the heat dissipation in the elastic member, and thus vary the primary deformation. If the variation is sufficient, there will be a sudden change if the secondary movement is produced by a labile member as above described, so that the device is particularly useful for showing sudden changes.

The construction of the device by which the primary deformation is produced can here be physically symmetrical, for instance, the heating element may be the central layer of a sandwich of two metallic members of identical form. The flowing medium flows past the face of one, while the other is provided with a heat insulating or reflecting layer.

We are aware of Patent No. 741,384 (National Research Development Corporation) which claims an electrothermal device which comprises essentially a metal or other heat expansible strip (which may be of composite form including a layer of relatively low heat conductivity or may comprise a low conductivity layer of paper, adhesive or cement sandwiched between two high conductivity layers) and at one face or side only thereof an electrical heating element (which element may be flexible and in close physical contact with the heat expansible strip, and

may be in the form of a strain gauge element of the type comprising a zig-zag conductor adhering to a paper or other thin backing and which may be produced by "printed circuit" technique) such that on passing sufficient current through the heating element the strip expands at its heating element face first and the strip is bowed until the temperature gradient from face to face of the strip becomes relatively small.

What we claim is:—

1. A device for obtaining a mechanical movement from the action of an electric current in which a relatively thin elastic heat conductive member has associated with it in relatively good heat conductive connection but electrically insulated from it, an electrical conductor of considerable dimensions in the surface direction of the elastic member but of small dimensions normal to the surface of the elastic member, the conductor being mounted on one face of the elastic member, or the conductor being mounted within the elastic member and the heat transmission properties of the elastic member being asymmetrical, so that in either case if a current heavy enough to produce a substantial heating effect is passed through the conductor, the heat is asymmetrically dissipated in the elastic member, causing it to undergo a primary change of form which is of a substantial character, while when such primary change of form takes place, mechanical forces come into action such that the elastic member is also caused to undergo a secondary change of form which is also substantial and in the same sense as the primary change so that the two changes supplement one another.

2. A device according to Claim 1 in which the primary change of form causes the elastic member to pass through a dead centre position at which forces come into action to produce the secondary changes.

3. A device according to Claim 2 in which the forces continue to hold the elastic member substantially in its changed form when the current ceases and the heating effect disappears.

4. A device according to Claim 3 in which the elastic member is in the form of a bar held under endwise pressure or of a disc held under radial pressure, the primary deformation causing it to change its form from one in which it is bowed to one side of the line or plane of the forces to one in which it is bowed to the other side of the line or plane of the forces.

5. A device according to Claim 1 in which the elastic heat conductive member is in a labile condition due to stresses locked within it so that it will spring suddenly from one configuration to another when the primary deformation takes place.

6. A device for obtaining a mechanical movement from the action of an electric current in which a relatively thin elastic bimetallic member has associated with it in relatively good heat conductive connection but electrically insulated from it, an electric conductor of considerable dimensions in the surface direction of the elastic member but of small dimensions normal to the surface of the elastic member, the conductor being mounted on one face of the elastic member, or the conductor being mounted within the elastic member and the heat transmission properties of the elastic member being asymmetrical, so that in either case if a current heavy enough to produce a substantial heating effect is passed through the conductor, the heat is asymmetrically dissipated in the elastic member, the arrangement being such that the part of the bimetallic member which is more highly heated by the asymmetric dissipation is the part of higher coefficient of expansion.

7. A device according to Claim 6 comprising two bimetallic members mutually arranged to compensate for ambient temperature changes, the conductor only dissipating heat into one of them.

8. A device according to Claim 7 in which two similar bimetallic members are similarly mounted parallel to one another so that they deform equally under ambient temperature changes, means being provided responsive to relative movement of the bimetallic members when one of them is deformed relatively to the other by heating of the conductor.

9. A device according to Claim 7 in which the two bimetallic members are cantilevers, the anchored end of one being carried in a slide linked to the free end of the other and guided to move in the direction in which the free end moves as the temperature of that cantilever changes.

10. A device according to any preceding claim in which the elastic member is of bar form and the conductor is of grid iron or similar form with its limbs transverse to the length of the elastic member.

11. A device according to any preceding claim in which the elastic member is of bar form and the conductor is of grid iron or similar form with its limbs set in the same direction as the length of the elastic member so that when the conductor is heated the limbs of the conductor are elastically strained by the elastic member.

12. A device according to any of Claims 1 to 9 in which the elastic member is of disc form and the conductor is of spiral form.

13. A device according to any of Claims 1 to 9 in which the elastic member is of disc form and the conductor is of double spiral form to avoid inductive effects.

14. A device according to any preceding

claim in which the elastic member is wholly of metal.

15. A device according to any of Claims 1 to 13 in which the elastic member is of laminated construction, at least one lamination of low heat conductivity being included to delay the dissipation of heat to the part of the member remote from the conductor.

16. A device according to any of Claims 1 to 14 in which the conductor is sandwiched between parts of the elastic member.

17. A device according to Claim 16 in which the asymmetric dissipation of heat is produced by the provision of a heat insulating layer on one side of the conductor.

18. A device according to Claim 16 as limited to any of Claims 1 to 5 in which the asymmetric dissipation of heat is produced by the provision of a layer of heat insulating or reflecting material on one side of the elastic member.

19. A device according to Claims 16, 17, or 18, in which a cooling liquid flows in contact with that side of the elastic member which is to be at lower temperature.

20. A device according to any preceding claim in which the conductor is produced by printing.

21. A device according to Claim 20 in which the conductor is produced in accordance with Patent No. 639,178.

22. A device for obtaining a mechanical movement from the action of an electric current substantially as described with reference to Figures 5 to 8 or Figures 12 and 13 of the accompanying drawings.

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PROVISIONAL SPECIFICATION.

Improvements in and relating to Devices for Obtaining a Mechanical Movement from the Action of an Electric Current.

We, TECHNOGRAPH PRINTED CIRCUITS LIMITED, a British Company, of 32 Shaftesbury Avenue, London, W.1, do hereby declare this invention to be described in the following statement:—

This invention relates to devices for obtaining mechanical movement from the action of an electric current, using the thermal effect of the current.

According to the invention an elastic heat-conductive member has associated with it in relatively good heat-conductive connection but electrically insulated from it, a conductor of considerable dimensions parallel with the elastic member but of comparatively small dimensions in a direction normal to the elastic member, the association of the elastic member and the conductor being such that if a current heavy enough to produce a substantial heat effect is passed through the conductor, the heat is asymmetrically dissipated in the elastic member, causing it to undergo a change of form which is considerable compared with the mere expansion which it would undergo if heated uniformly. The asymmetrical dissipation of heat can be produced by the physical location of the conductor, for example on one long face of a bar-like member. It can also be produced or assisted by using an elastic bar of non-uniform heat-conductive nature, for instance of laminated structure with one or more of the laminations of less heat conductivity than others. Or again, the conductor can be symmetrically disposed physically in relation to an elastic member of uniform heat-conductivity, but with different boundary conditions at the faces on opposite sides of the conductor, for example a heat insulating or reflecting layer on one side and a radiating or highly heat-conductive or absorbing layer on the other face, for instance a flowing liquid.

In many cases the elastic heat-conductive bar will primarily be of metal, though if a laminated construction is used, the metal will be laminated with a material usually non-metallic which has low heat conductivity.

In use in many cases the conductor will only transmit current when it is desired to produce the change of form for some purposes to be achieved or some indication to be given. But cases are also possible in which the conductor normally carries current and the device normally remains in an equilibrium condition with its external surroundings; it will then undergo a change of form when a change occurs in the surroundings which upsets the equilibrium conditions. It is still necessary that there should be some asymmetry in the heat dissipation in the one condition or the other because without this there would be no change of form.

It will be understood that the above-described section of the conductor constituting a heating element and the fact that the elastic member with which it is associated is in general a good conductor of heat, enables a comparatively heavy current to be used, and therefore a considerable heating effect to be achieved; moreover, an elastic

member is able to undergo deformation and recover its original form, or substantially recover its original form, many times without suffering damage.

It will also be understood that in the form above described if the current is maintained the deformation will reach a certain value and then, as the heating of the elastic member becomes more uniform, some of the deformation will disappear; after a certain time an equilibrium condition will be reached under which there will still be a certain deformation because the metallic member is being heated asymmetrically, but just because a good conductor of heat is used, when equilibrium conditions are reached the deformation will not be very great.

A particular property of a device of this character is that it is substantially insensitive to ambient temperature conditions. It is true that if the heating element and the elastic member are of different metals the asymmetry of the arrangement would theoretically cause slight deformations with ambient temperature changes, but just because the conductor is thin in a direction normal to the elastic member, any constraints which it exerts due to differences of thermal co-efficient of expansion would have little effect on the elastic member, especially, if, as may be desirable, the form of the conductor is made such as to keep such constrains to a low value. This property of the device makes it useful for many purposes where, for example, a bimetallic strip heated by the passage of a current is not suitable. In many cases, however, it can replace the functions of bimetallic elements with advantage.

A further development consists in making the elastic member itself a bimetallic strip, bar or the like, the heating element being arranged so that the greatest heating effect due to the heating element is on that side of the bimetallic member which expands at the greater rate. In this way, a substantially greater deformation for a given power input is obtained, and a greater force can be obtained. Thus, a more efficient device can be produced, or for a given movement a more rapid response. Independence of ambient temperature conditions can still be obtained by providing a second bimetallic strip having the same law of deformation as the first, but without a heating element and using it to compensate those movements of the first bimetallic strip which are due to ambient temperature changes. For example, if two bimetallic cantilevers are arranged in parallel and their free ends joined by a tension or a compression member, then no changes in the force exerted on this member will occur under ambient temperature changes, but they will occur if a current is passed through the heating element. Or one of the bimetallic members may be used to shift the clamped end of the other, the two being arranged in opposite directions so that the shift caused by the first is exactly equal and opposite to the shift of the free end of the second under ambient temperature changes.

Other relative arrangements on the same principles are also possible. In the case of bimetallic strips as long as the heating element is in action there will be a considerable deformation even when equilibrium is reached.

There will, in general, be a time lag between the switching on of current and the maximum deformation and this, in turn, will put a limit on the frequency at which the device can be used, but the time lag is small enough and the frequency high enough for the device to be useful for very many purposes. The actual time lag can be varied by choice of the dimensions, materials and actual construction of the elastic member and the heating element.

The extent of deformation can be substantially increased by interposing a thin layer of heat insulating material at a place within the elastic member which hinders the transmission of heat to that part of the metallic member which in any case would be last heated during the passage of current through the conductor.

This development could be used in association with a bimetallic member which in this case would become a sandwich of two different metals on opposite sides of the layer of heat insulating material.

By way of example, the elastic member can be of bar form with the conductor secured on one long face; desirably, the conductor extends over a substantial part, or even the whole of the long side of the bar. The deformation in this case is not very great, but the time lag is very small. If the deformation is to be increased by the use of a bimetallic member or of a layer of insulation, the junction between the two metals or the layer of insulation can extend within the bar parallel with the face on which the conductor is provided; it can, for instance, be half-way through the thickness so that in effect in the latter case the bar becomes a sandwich of two bars with a thin layer of thermal insulation between them and with an insulated conductor secured on the exposed long face of one of the bars. With such constructions, the deformation occurring on heating is a change of curvature of the bar in planes normal to the face carrying the conductor. Generally speaking, the bar might be straight when no current is flowing, and it will then become curved. If a bar of this kind is clamped at one end the other end will move laterally when the

deformation occurs; if it is clamped in the middle, both ends will move laterally.

It is also possible to make a sandwich construction in which the conductor is between two bars; on one side the conductor is secured as close to the bar as is compatible with electrical insulation, while on the other side heat insulation is provided, so that once again the composite bar is heated asymmetrically and will deform similarly to the two constructions described above. It will be understood that with these sandwich constructions, though the deformation is greater, the time lag is also greater than in the case of a simple bar.

Another possible form is a disc, in which case the conductor may take a spiral form or, preferably, a double spiral so as to avoid inductive effects. The simple elastic, usually metallic, disc can have the conductor on one face or a bimetallic or either of the above described sandwich constructions can be applied. In all these forms the deformation will be a change in convexity, including the case in which the disc is normally flat and is rendered convex when the current passes.

In all the forms above described, except where the heater is on a bimetallic member the metallic member returns towards its original form as the current continues to flow until equilibrium is reached, while when the current is cut off it will return to its original form, or substantially so. Cases may arise in which it is desired that the member once having been deformed should remain so after the current has been cut off and until some other operation, generally a mechanical operation, is performed. This can be effected by preloading the member in a condition and under a load such that when the current passes the member is moved over a dead centre. For example, a bar can be held under endwise pressure, or a disc under radial pressure, which bows it slightly in a direction opposite to the bowing produced by the heating effect; then when heating has bowed it the other way, the end pressure or radial pressure will continue to hold it bowed in this opposite direction after the current has been cut off.

Another possibility is to use an elastic member generally of metal which by means of stresses locked in the material is in a labile condition. Known devices of this kind are oil-can bottoms and snap lids in the case of discs and the blades of micro switches in the case of members of bar or strip form. By providing a device of this character with a heating element in accordance with the present invention a much increased deformation can be obtained but in this case, in general, when the heating is stopped the device will return to its starting position. In these cases the greater part of the movement takes place suddenly which may be of advantage when the device is used for electric switching, e.g., as a relay.

Another possible development is to provide a bar member or disc of the simple or first sandwich form, with a conductor on both sides; or of the second sandwich form with a conductor on both sides of the thermal insulating layer. In this case, only one conductor will be energised at a time, but by choosing which is energised, the member can be deformed to one side or the other.

The conductor itself can be produced in various ways. It is very conveniently produced by printing, since a printed conductor can easily be given the necessary characteristics of thinness normal to the surface on which it is printed, and any desired width on the surface. And of printed conductors, conductors produced in accordance with Patent No. 639,178 are particularly well adapted to the purpose in view. It has been found, for example, that a conductor of cupronickel foil of $\frac{1}{2}$ mil. thick of a zig-zag form produced in this way on a thin support of a synthetic resin, e.g., an epoxy resin as sold under the Registered Trade Mark "Araldite", and secured to a metallic bar member by a cement such as used in the securing of electrical resistance strain gauges can without difficulty dissipate into the metal bar the heat derived from a loading of well over 10 watts per square inch.

As above noted, it may be desirable to arrange the conductor in such a way that it is not harmed and does not exercise substantial elastic constraint on the metallic member. This can be done by arranging the conductor in a zig-zag or grid iron pattern in which the limbs extend transverse to the length of the metallic member. In some cases, however, it may be desirable that the conductor should be elastically strained as the member deforms. In this case, the grid iron or zig-zag limbs would extend lengthwise of the metallic bar, in which case the heating and deformation should be limited to a value which avoids damage. This arrangement may be used, for instance, where it is desired to keep a check at some remote point on the amount of deformation, or use this indication of the amount of deformation to control another circuit. This can be done by using the conductor not only as a heating element but also to actuate the sort of circuit which is used with a strain gauge. However, the former arrangement in which the grid iron or zig-zag limbs are transverse to the length of the metallic member can also be used to give a remote indication or control by using the conductor not only as a heating element but also as a resistance thermometer. In the former case, the temperature of the conductor, as well as the strain of the conductor, would affect the

readings and must therefore be taken into account. In the latter case, the temperature of the conductor can be ascertained but no direct indication of the amount of deformation.

A valuable feature of the device according to the invention is that it can exert considerable forces because in general metals have a high modulus of elasticity and the forces exerted are directly related to this modulus. On the other hand, relatively large movements are possible by the use of bimetallic and laminated members.

The device according to the invention can be used for many purposes. In general it can be used for example to replace a bimetallic strip wherever such a strip is heated by the passage of an electric current. The device can be used as a relay in which case it will usually be of lighter and cheaper construction than an electromagnetic relay. In a larger size it can be used as a contactor to control heavier currents than can be directly controlled by a relay just because as above pointed out it is capable of developing large forces. It can be used for the construction of switches and relays with a wide range of time lag from very small up to such long delays as would not readily be achieved with ordinary electromagnetic relays. In the case of relays and switches a quick closing and opening action, independent of the actual time lag, and a large break can be obtained by the use of an elastic member in a labile condition as above described. The device can be used as an automatic interrupter of comparatively low frequency by making its movements control the flow of current through its own heater.

The device can be used as a circuit breaker which remains open once it has operated until it is re-set manually, or by some other piece of apparatus. For this purpose, the type described above which is preloaded and moves over a dead centre when current passes, would be used.

Since the response of the device depends on the current in the heating element a device according to the invention can be made to distinguish between low currents and high currents and this is especially valuable in an automatic circuit breaker used for protective purposes. The device can also be used as an indicator in the like circumstances where it is not necessary that a circuit should be broken but simply that an indication should be given when there is a sudden increase in current in a circuit, or a part of a circuit; for example, it can be used to indicate the occurrence of a temporary short circuit. Here again, the use of an elastic member in a labile condition may be of advantage in particular cases. The device can similarly be used to indicate the breakage of a current carrying element where that element is included in a bridge circuit. If the element breaks the bridge is thrown out of balance by a vast amount because a finite resistance in one arm is suddenly made infinite. There is accordingly an immediate substantial current increase in the output diagonal of the bridge. If the heater of a device according to the invention is included in the diagonal, this sudden increase will actuate the device, thus giving a remote signal, or causing some operation to be performed, whereas the normal current in the diagonal while the bridge is only out of balance to the extent caused by resistance variations in the arms will not affect it.

Another possible use for the device according to the invention is as an indicator of the flow or temperature of a flowing medium such as a liquid. In this case, the flowing medium will influence the heat carried away from one face of the device. For instance, it may flow past it and the heating element will usually be continuously energised. Changes in the rate of flow and/or the temperature of the medium will influence the asymmetry of the heat dissipation in the elastic member, and thus cause deformations which can be indicated or recorded as above-mentioned. In this connection, the device is particularly useful for showing sudden changes.

The construction of the device can here be physically symmetrical, for instance, the heating element may be the central layer of a sandwich of two metallic members of identical form. The flowing medium flows past the face of one, while the other is provided with a heat insulated or reflecting layer.

Yet another possible use for the invention is the application of a mechanical brake. Here the elastic member may constitute a brake shoe provided with a liner of suitable braking material for the particular purpose in view and the deformation caused by the passage of current through the heating element can apply the brake shoe to the element to be braked.

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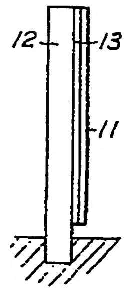


Fig. 1.

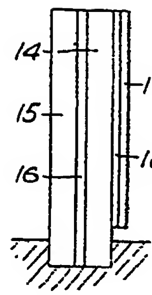


Fig. 2.

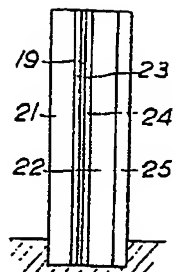


Fig. 3.

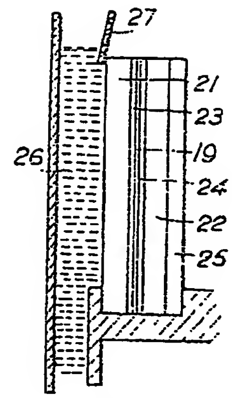
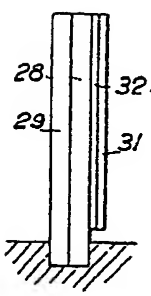


Fig. 4.



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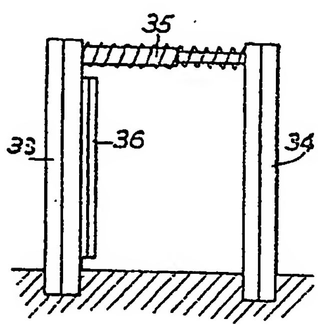

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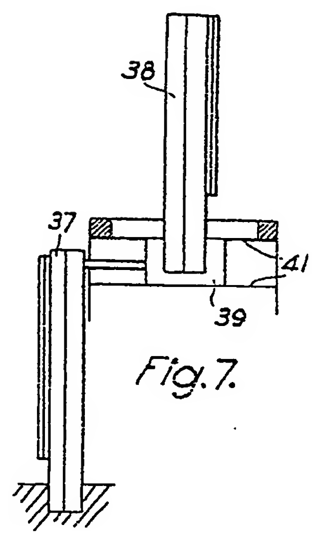
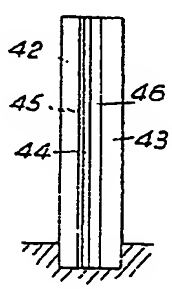


Fig. 7.



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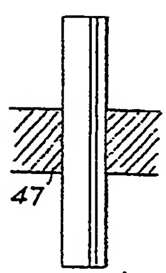

Fig. 9.

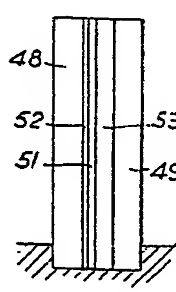

Fig. 10.

792,145 COMPLETE SPECIFICATION
2 SHEETS

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SHEETS 1 & 2

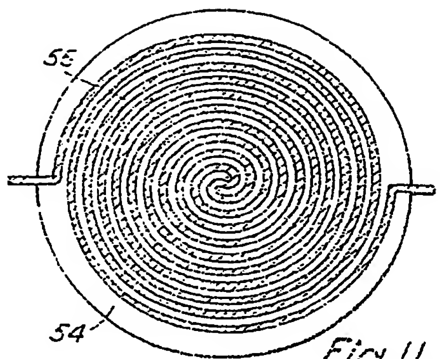

Fig. 11.

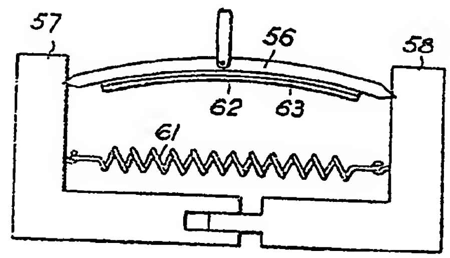

Fig. 12.

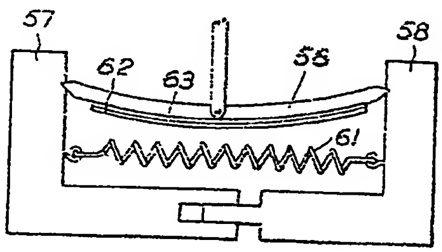

Fig. 13.

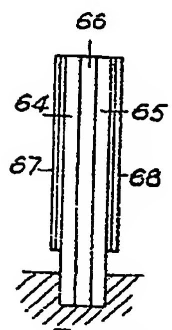

Fig. 14.

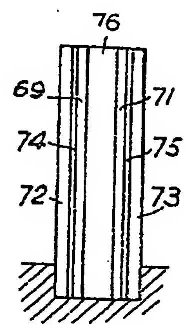

Fig. 15.

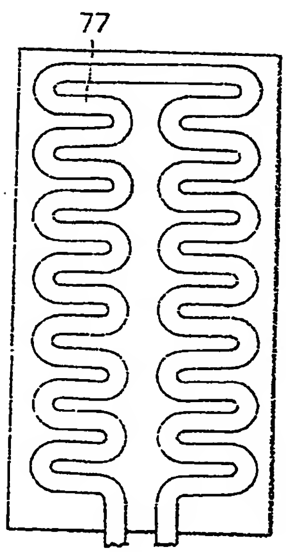

Fig. 16.

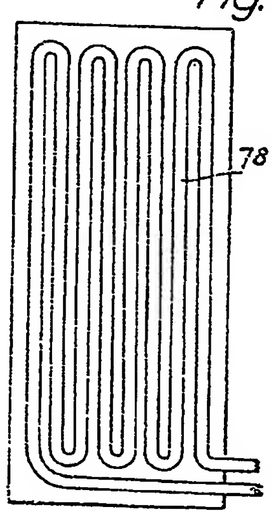

Fig. 17.

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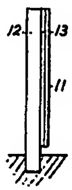

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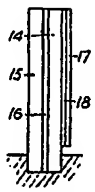
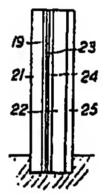


Fig.2.



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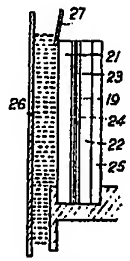


Fig.4.

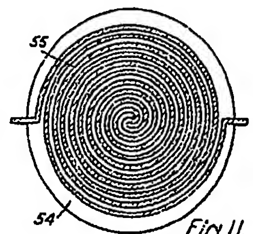
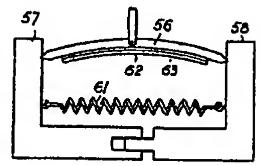


Fig.11.



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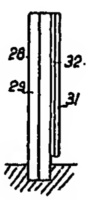

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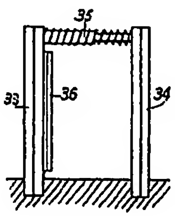

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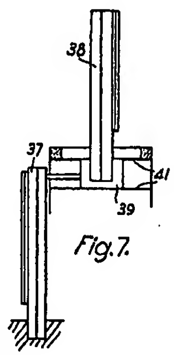

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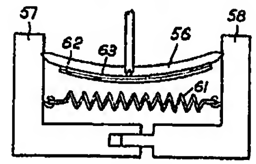

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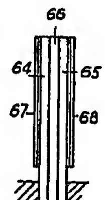

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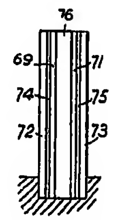

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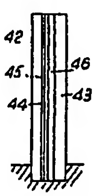

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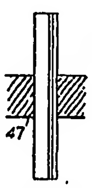


Fig.9.

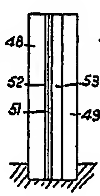
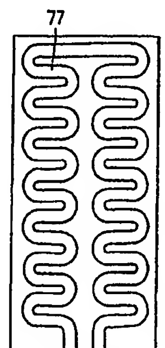


Fig.10.



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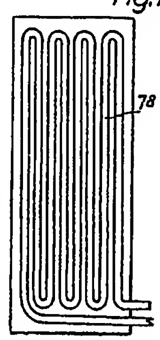

Fig.17.